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# PRECIPITATION ESTIMATES IN THE GREAT LAKES DRAINAGE BASINS

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## ABSTRACT

Precipitation estimates from various sources for the different Great Lakes drainage basins are reviewed. To check the comparative accuracy of the estimates, they are correlated with the net basin supply (runoff) values for each basin. The best correspondence between net basin supply and precipitation is indicated for the smaller basins—Erie and Ontario—and the poorest for the larger basins, Michigan-Huron and Superior. It appears that reasons for the poorer relationship in the case of the larger basins include the use of calendar-year, rather than water-year, net basin supply and precipitation data, and the use of a varying number instead of a fixed-number of stations. The use of a fixed number of stations appears to eliminate the possibility of the inclusion of time trend errors.

## 1. INTRODUCTION

The Great Lakes are the earth's greatest concentration of fresh water. In table 1 the water and land areas of the drainage basins of the various Great Lakes are ranked in order of total area.

From time to time, especially during periods of predominantly high or low lake levels, or during periods of controversy concerning diversion of water from the Great Lakes, there has been considerable interest in hydrologic problems of the Great Lakes. Since precipitation is the source of the water which comprises the Lakes, accurate rainfall estimates are one of the basic ingredients of any study of the hydrologic cycle involving the Great Lakes.

TABLE 1.—*Areas of drainage basins of the various Great Lakes.*

| Lake | Areas (sq. mi.) | | | Ratio of land to water area | Percent of total combined area |
|---|---|---|---|---|---|
| | Water | Land | Combined | | |
| Ontario | 7,520 | 27,280 | 34,800 | 3.6:1 | 11.8 |
| Erie-St. Clair [1] | 10,420 | 29,500 | 39,920 | 2.8:1 | 13.5 |
| Superior | 31,820 | 48,180 | 80,000 | 1.5:1 | 27.1 |
| Michigan-Huron [2] | 45,410 | 95,070 | 140,480 | 2.1:1 | 47.6 |
| Total | 95,170 | 200,030 | 295,200 | 2.1:1 (average) | 100.1 |

[1] The Erie-St. Clair basin will hereafter be referred to as the Erie basin in this study.
[2] Lakes Michigan and Huron have the same elevation because of the broad and deep connection through the Straits of Mackinac, and are usually considered hydraulically as one lake.

A better understanding of the relationship in recent years between precipitation and runoff from the Great Lakes basins could also possibly lead to more precise information concerning the rainfall in the Great Lakes basins prior to the 1870's, since records of Great Lakes levels extend back to 1860 and earlier, while the earliest precipitation estimates for any Great Lakes basin begin in the 1870's. It has been pointed out [8] that lakes integrate rainfall effects over wide areas and are a statistically more reliable sample than a rain gage measurement which is supposed to represent the precipitation over many square miles. However, it may never be possible to make a precise determination of rainfall from early records of Great Lakes levels, because of the uncertainty as to the effect of cultural changes in the drainage basins. Likewise, it may never be possible to make a precise water budget study of the Great Lakes, tempting though it may be, because of uncertainty as to some of the factors, including the exact amount of precipitation assumed to be represented by any precipitation estimate.

It is the purpose of this study to review, and check for comparative accuracy, some of the precipitation estimates which have been made for the Great Lakes drainage basins, and to determine which, if any, are most suitable for use in hydrologic studies.

## 2. PRECIPITATION MEASUREMENTS

The amount of precipitation caught in an 8-inch, or larger, rain gage is a somewhat uncertain estimate of the amount of precipitation in an area which may be billions of times as large (ratio of area for average density of rain gages in the United States to area of rain gage). Nevertheless, it has been shown [6] that a high degree of reliability may be assumed even when the mean rainfall over a small area is determined from a single station, provided the station is within the area.

Instrumental errors may be quite large and cumulative [8], and the rain gage catch may be deficient during periods of high winds [5] and snow [8]. (In Canada, snow depths are assumed to represent the amount of melted precipitation on a 10:1 ratio.) However, it has been pointed out [5] that in many hydrologic studies, the fact that the rainfall indicated by a rain gage is deficient is of little significance. "In rainfall-runoff studies, a systematic error in measuring rainfall might be buried in one of the empirical constants; it is only necessary that the measured rainfall be correlated in a systematic manner with the actual rainfall." [5].

## 3. PRECIPITATION ESTIMATES

There is some difficulty and frustration in attempting to develop long-term precipitation estimates for the Great Lakes drainage basins, since the basins are not identical with any geographic subdivision, and because comparatively few long-period precipitation records are available. However, Day [4] has pointed out that when the official collection of daily weather statistics, including measured precipitation, began in the United States in the latter part of 1870, more stations per unit area were established in the Great Lakes region than in other parts of the country. All of the four principal drainage basins also include areas of Canada and monthly amounts of precipitation for Canadian stations must usually be summed to obtain the annual amounts ordinarily used in hydrologic studies.

Grunsky [7] derived precipitation estimates for the period 1871 to 1923 for the Superior, Michigan-Huron, and Erie basins. The number of stations used in each basin was 9, 31, and 14, respectively. A considerable amount of the data before 1890 was interpolated, especially for stations in the Superior basin. Grunsky did not attempt to relate his rainfall estimates to lake levels, or any water supply factor, but other investigators [10] were unsuccessful in an attempt to show a correlation between Grunsky's precipitation estimates and Michigan-Huron lake levels.

Horton [7] used Grunsky's data to obtain seasonal estimates of precipitation on the same basins, and also derived annual amounts on a water-year basis, beginning November 1. Horton's values are slightly higher than Grunsky's, because of a correction applied for deficiency of measured snowfall. Horton also developed precipitation estimates for the water areas of the Great Lakes, with the exception of Ontario, and made a graphical comparison of 5-year means of rainfall with lake levels and water supply factors for each of the basins, but did not indicate any year-to-year correlations.

Day [4] made a comprehensive study of the precipitation in the Great Lakes area for the period 1875 to 1924, and included a discussion of the levels of the lakes and their relation to annual precipitation. He concluded that: "The levels seem to be closely related to the quantity of precipitation, delays of a year or more often appearing in the response of the levels, since the runoff is not immediate." The number of stations used by Day to derive the estimates of precipitation in each basin were as follows: Superior, 18; Michigan, 23; Huron, 16; Erie, 21; Ontario, 16; total 94 (eliminating duplications, 91). As in the case of Grunsky's study, some of the data prior to around 1890 were interpolated, especially in the case of many of the Superior stations. It was indicated by Day that each station, even though its record was not continuous, should nevertheless represent a distinctive area, embracing frequently several stations with records for different periods, but so located as to justify the assumption that they represented the precipitation of the district. (It has been pointed out [8] that there is a regional consistency in precipitation patterns for long periods of time, but this consistency becomes less pronounced for shorter periods.)

Day's precipitation estimates for the Erie basin for the period 1875 to 1924, and extended from 1925 to 1952, were used in a recent study [3] involving the water balance of Lake Erie to determine the probable Michigan-Huron discharge. Another study by the same author [2] used precipitation estimates by the U.S. Lake Survey, Corps of Engineers, for the Michigan-Huron basin, to show a computable relationship between precipitation and lake levels, and also an apparent lag between precipitation and its effect.

The U.S. Lake Survey has developed precipitation estimates for the various Great Lakes basins, beginning with 1900, with some estimates extending back to around 1883. These estimates do not use a fixed, but rather include a varying, number of stations. For example, the total number of stations used in the Michigan basin ranged from 91 in 1900 to 421 in 1955; and in the Huron basin from 109 in 1925 to 320 in 1950. (At present approximately 300 stations are used in deriving the precipitation estimates for each of these basins.) It has been shown [11] that the use of increasing numbers of rain gages with time may introduce an increasing bias in estimates of watershed precipitation.

One additional set of Great Lakes precipitation estimates that has been referred to in the literature [1, 9] was developed by Canadian agencies. These estimates, from around 1870 to 1934, were computed by the Hydrographic Service of the Department of Mines and Technical Surveys, and included only a few stations in the early part of the period, while several dozen were used for most of the basins in the latter part of the period. Other values for 1934 through 1956 were determined by the Meteorological Branch, Department of Transport. These included Canadian stations only and the "normals" for all United States stations available in the various basins were combined with the Canadian data, apparently since the purpose was to derive long-term average precipitation amounts, rather than precise values for given years.

One difficulty involved in using some of the precipitation estimates for the Michigan and Huron basins is that the water supply factors cannot be as readily separated for the two basins as the precipitation estimates have been. For example, the figures for the outflow from the outlet of Lake Huron include not only the runoff from the land and water areas of the Huron basin, but also corresponding amounts from the Michigan basin as well; and separate discharge values for the Michigan basin are not available. It would be desirable, and probably somewhat more accurate, to use a combined precipitation estimate for the Michigan-Huron basin, in preference to using arithmetic averages of the Michigan and Huron precipitation estimates, as was done in the study involving this basin previously referred to.

To provide a check on the comparative accuracy of the four sets of precipitation estimates described, and to determine whether any time trend errors are involved, the estimates for each basin were correlated with the net basin supply[1] for the corresponding basin. (Net basin supply (N) is defined as outflow (O) minus inflow (I) plus change in lake level (storage, S) or $N=O-I+S$, and is equivalent to the runoff for each basin, or equal to precipitation minus water losses.) The results of the correlations of the annual values for each basin for various periods are indicated in table 2.

Time trend errors are indicated in the case of the Lake Survey data for Michigan-Huron and Superior, and for the Canadian estimates for Erie, since larger correlation coefficients are obtained when the last two digits of the year are included as one of the variables (1900 to 1952). It was, therefore, decided to use a fixed number of stations by extending and modifying the precipitation estimates of Day, in order to determine whether the use of a fixed number of stations would eliminate the time trend errors. This was accomplished for the various basins as follows:

(1) Superior. In this basin four of the stations outside the drainage basin were omitted. Otherwise, the same stations used by Day, totalling 14, were also used, insofar as possible. In case of missing data, or changes in locations of stations, the precipitation of a nearby station was substituted.

(2) Michigan-Huron. In this basin four of the stations outside the drainage basin were omitted. Lansing, Mich. was used only once; it was used by Day in deriving the estimates for both the Michigan and Huron basins. Sault Ste. Marie, Mich. was added; this station was also used for the Superior basin. The average of the 35 stations was considered as representing the precipitation estimate for the Michigan-Huron basin.

(3) Erie. For this basin, the same 21 stations used by Day were also used, with the limitations described above for the Superior basin.

(4) Ontario. In this basin some care was taken to make certain that changes in locations of stations did not also involve significant differences in the precipitation regime. A change of a short distance in some parts of this basin, especially if it involved a change in elevation, could result in a substantially different precipitation amount. For this reason, several changes in stations were made, and a total of 14 stations was used to derive the precipitation estimates for the basin.

The precipitation estimates thus obtained from 1875 to 1952 (not shown) were also correlated with the net basin supply values, with the results indicated in table 2. No time trend errors are indicated for any of the basins. However, it should be pointed out that not all of the other precipitation estimates described in this study were computed with the intention of eliminating time trend errors. For example, the Lake Survey precipitation values were apparently derived in order to obtain the most accurate value for each year through the use of a large number of stations, and should be more accurate in any given year than estimates based upon a smaller number of stations.

[1] Net basin supply data for the various Great Lakes basins were furnished through the cooperation of the U.S. Lake Survey, Corps of Engineers, Detroit, Mich. (values available through 1952 only). Data for Superior, Michigan-Huron, and Erie were computed by the Lake Survey in 1953, and data for Ontario were computed in 1957.

TABLE 2.—*Correlation of net basin supply and precipitation estimates (annual values, calendar-year basis, unless otherwise indicated)*

| | SUPERIOR | | | | | MICHIGAN-HURON | | | | | ERIE | | | | | ONTARIO | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (1) | (2) | (3) | (4) | (5) | (1) | (2) | (3) | (4) | (5) | (1) | (2) | (3) | (4) | (5) |
| Grunsky | .17 | .79 | — | — | — | .70* | .46 | — | — | — | .52* | .55 | — | — | — | — | — | — | — | — |
| Day | .29 | .66 | — | — | — | .72* | .43 | — | — | — | .67* | .67 | — | — | — | .68 | .62 | — | — | — |
| Lake Survey | — | .69 | .72 | .68 | .72 | — | .42 | .78 | .66 | .68 | — | .74 | .91 | .85 | .85 | — | .72 | .86 | .82 | .82 |
| Canadian | .41 | .71 | .64 | .67 | .68 | .72* | .54 | — | — | — | .64* | .71 | .87 | .77 | .83 | .56 | .66 | .83 | .79 | .79 |
| Brunk (Day) | .28 | .71 | .76 | .75 | .75 | .72* | .48 | .82 | .73 | .73 | (.67*) | (.67) | .90 | .83 | .83 | .63 | .66 | .83 | .78 | .78 |
| Lake Survey (water year) | — | — | .81 | — | — | — | — | .82 | — | — | — | — | .89 | — | — | — | — | .88 | — | — |

NOTES:
(1)=1875 to 1899
(2)=1900 to 1923
(3)=1924 to 1952
(4)=1900 to 1952
(5)=1900 to 1952, including last two digits of year as a variable in the correlation.
Underlined values are indicated to be significant at the 1 percent level of probability.
*These correlation coefficients are of doubtful value because of doubt [3] as to accuracy of net basin supply values for Michigan-Huron and Erie in the period 1875 to 1899.

It has been shown [3] that a somewhat better correlation between net basin supply and precipitation on the Michigan-Huron basin is indicated when correlations are on a water-year, rather than on a calendar-year, basis. It appears that the effect of snow, which accumulates in the late months of a calendar year and melts in the following year is thereby eliminated. Since it was not possible to convert Day's precipitation data, (which were on a calendar-year basis and did not include monthly values) to a water-year basis, the Lake Survey net basin supply and precipitation values were changed to a water-year basis (beginning with October 1).

The correlations of these net basin supply and precipitation values on a water-year basis for the period 1924 to 1952 are indicated in table 2. Because of generally higher correlations indicated on a water-year basis than on an annual basis, it appears that the snowmelt factor is a problem to be reckoned with, except on the Erie basin. In this basin, the snow cover is generally light and sporadic, at least in that portion of the winter prior to January 1.

## 4. CONCLUSIONS

It has not been the purpose of this study to provide the last word on precipitation estimates for the Great Lakes basins, but only to review and compare various estimates, and to point out some of the desirable characteristics which would make estimates most suitable and accurate for use in hydrologic studies, especially those involving the use of long-period precipitation estimates.

Considering the fact that poor correlations might be due to inaccuracies in either the measurement of precipitation, or in the factors used in the computation of the net basin supply values, but also the fact that there appears to be little or no reason to doubt the comparative accuracy of the precipitation measurements, or change in accuracy with time (except in the case of interpolated data), the following observations and/or conclusions can be made (among others) from a consideration of the correlations:

(1) Little confidence can be placed in the accuracy of any of the precipitation estimates for the Superior basin in the period 1875 to 1899 because of the very poor correlations indicated. This is probably on account of the extensive use of interpolated precipitation data in this basin before about 1890; although the possibilities of inaccuracies in the net basin supply data, or a change in the precipitation-runoff relationship, cannot be entirely ignored.

(2) Because of the generally higher correlations in the most recent period, 1924 to 1952, it appears that the accuracy of some of the data used in the computation of the net basin supply values has increased steadily with time.

(3) Because of the much poorer correspondence of net basin supply and precipitation for the period 1900 to 1923 for Michigan-Huron than for any of the other basins, it appears that there may have been a change in the accuracy of one or more of the factors involved in the determination of the net basin supply values for this basin in this period.

(4) In spite of the use of a smaller number of stations Day's estimates, modified and extended, are comparatively more accurate than other estimates for the Superior and Michigan-Huron basins in the years 1900 to 1952.

(5) In the Erie and Ontario basins, the Lake Survey estimates are somewhat more accurate than any of the other estimates for the years 1900 to 1952.

(6) It, therefore, appears that for use in hydrologic studies the most consistent estimates for the Michigan-Huron and Superior basins can be developed by the use of a fixed number of stations, and that on any basin where snowmelt is a factor, the precipitation estmates and other data used should be on a water-year, rather than on a calendar-year, basis.

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